

Information Technology and Quantitative Management (ITQM2013)

Scenario simulation and policy analysis on energy development in Qinghai Province

Yuying Yang^{a,b}, Xiaolei Sun^{a,*}, Xiaoqian Zhu^{a,b}, Yongjia Xie^{a,b}^a Institute of Policy and Management, Chinese Academy of Sciences, Beijing 100190, P.R.China^b University of Chinese Academy of Sciences, Beijing 100039, P.R.China

Abstract

Solving China's severe energy problems relies on the efficient implementation of energy-related policies at the provincial level. On the context of 12th Five-Year Plan, most provinces' energy developments are faced with the double pressures, that is, the rapid economy development and energy conservation. Thus, it is necessary to explore the scenarios of energy, economic and social development on the provincial level, especially in western developing provinces. This paper proposes a framework of economy and energy system including three major components: economy growth, population and energy intensity, to identify the regional energy balance and CO₂ emission by 2015. With an application to Qinghai Province, policies related to energy development can be classified into three subcategories: economic and social development, energy development, and energy saving policies. Then, five scenarios are set and simulated to explore the energy balance and CO₂ emission under the constraints of economic growth and energy intensity. Results show that in Qinghai, energy demands will increase by 90.37% in 2015 with a significant adjustment in industrial structure; and the implementation of the energy saving policies in Qinghai province is necessary. Besides, increasing production of clean energy can significantly reduce the consumption of fossil fuels and the environmental impact.

© 2013 The Authors. Published by Elsevier B.V. Open access under [CC BY-NC-ND license](https://creativecommons.org/licenses/by-nc-nd/4.0/).

Selection and peer-review under responsibility of the organizers of the 2013 International Conference on Information Technology and Quantitative Management

Keyword: energy demand and supply, energy conservation, scenario simulation, energy policy

1. Introduction

Energy is a vital input for economic development, and planning its development has always been a quite important issue for energy optimization and management. Various policies of energy planning have been put forward by Chinese central and provincial governments at the beginning of the 12th Five-Year Plan period, aiming at energy saving and environment protection. How to coordinate the energy and economy development has been an important issue that will constrain sustainable economic and social development.

Energy balance is mainly determined by economy development, energy efficiency and resource. The economic and energy-related policies put forward by central or the provincial government will influence the energy demand and supply. Facing the pressure on energy security and increasingly severe environmental problems, Chinese central government has set that energy intensity should be reduced 16% over the period 2011-2015 (from 1.034 to 0.869 tce/10,000RMB GDP, in 2005 prices), and this would save 6700 million tons standard coal equivalent in the five years in "Energy saving 12th Five-Year Plan". Lots of studies focus on the China's energy problems on the country level [1,2,3,4,5,6,7,8]. However, the practical problems facing China, such as economy development, resource

*Corresponding author. Tel: +86-10-59358806;

E-mail address: xlsun@casipm.ac.cn

constraints, energy conservation and environmental pollution, can only be solved by relying on each province. In response to the goal issued by central government, most provinces have put forward their own energy planning during 2011-2015. Therefore, it is necessary to study the energy problems at the provincial level.

For most provinces in China, energy development faces the double pressure, supporting the quick economic growth and realizing energy saving and emission reduction. Moreover, the pressure is severer for western developing provinces. These provinces, first and foremost, need facilitate economic growth to realize the well-off society along with eastern developed provinces, and meanwhile save energy and reduce carbon emission. Thus, this paper focuses on the energy development of western developing provinces, and attempts to explore its energy balance and CO₂ emission in the period of 12th Five-Year Plan with an application to Qinghai province, who has set a goal of 10% reduction of energy intensity at a provincial level and 16% decreasing in industry energy intensity during 12th Five-Year Plan period (FYP, 2011-2015)¹.

Qinghai province is a typical western developing province, and its development has quite distinguished characteristic. On one hand, the regional domestic production (RDP) is low and the RDP per capita ranks 21th among China's thirty-one provinces and cities in 2011. Qinghai Province has achieved a much higher economic growth rate than the average of the whole country during the 11th Five-Year Plan period, and has put forward a goal of an average annual economic growth rate of 12% in the 12th Five-Year Plan, much higher than the national goal of the average annual economic growth rate of 7%. On the other hand, Qinghai's energy intensity in 2011 was 2.081 tons standard coal equivalent per 10000-Yuan RDP, 2.6 times higher than the national average energy intensity and the second highest among the provinces in 2011. Qinghai's low energy efficiency was linked to the very high share of heavy industry. The rapid economy growth and the low efficiency of energy consumption posed great pressure on the energy supply and environment protection. It is necessary for Qinghai's energy balance and CO₂ emission to implement energy saving policy.

In light of the higher economic growth rate and low energy efficiency in Qinghai Province, this research tries to examine how Qinghai's economy development and energy saving policy will influence on its energy balance and CO₂ emission during the 12th Five-Year Plan period through scenario simulation. A number of models are developed for the efficient energy planning and energy resource forecasting and optimizing, such as multiple objective programming technique, ARIMA models, ANN models, input-output models and bottom up models[9,10,11,12,13]. However, when scenario simulation and policy analysis are implemented on energy development in Qinghai Province, the models above mentioned have some limitations due to data availability and systematicness of energy and economy. Thus, this paper proposed a three-component framework, and a system dynamic model is built to perform simulations of energy balance and CO₂ emission by 2015. System dynamic model is a quite useful tool to model non-linear complex energy system [14,15].

This rest of paper is organized as follows. In section 2, we propose the research framework and set five scenarios, followed by the system dynamics model to simulate the scenarios. The data and results are presented in Section 3, and then in Section 4 we conclude.

2. The methodology

2.1. The research framework

Energy consumption and CO₂ emission under the constraints of economic growth and energy intensity is our focus. A framework including three main components is proposed and displayed in Fig 1. Three components include economy development, population growth and energy intensity, which are the major driving factors of energy consumption.

¹ Views of Qinghai Provincial Government on Strengthening Energy-saving Work during 12th Five-Year period

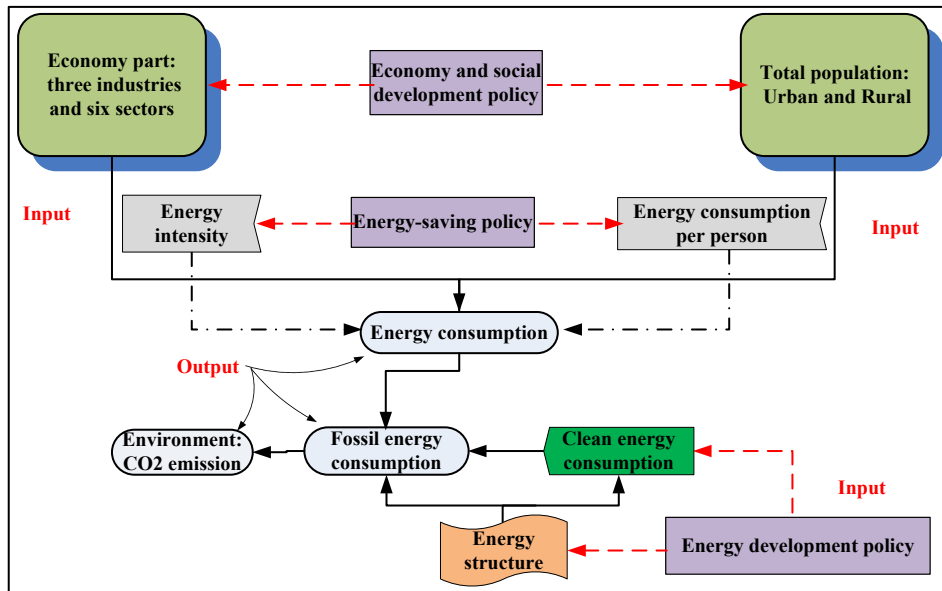


Fig.1. The sketch map of research framework

Energy consumption can be divided into clean energy consumption and fossil energy consumption. The former represents the use of hydropower, solar and other carbon-free resources. The economy component is divided into three industries and six sectors according to China's GDP accounting standards and Qinghai's overall energy balance sheet accounting standards in their Statistical Yearbook. The terminal energy consumption is gained through economy value added and energy intensity, and primary energy consumption can be achieved by multiply a coefficient. The terminal energy consumption is comprised of four parts: primary industry consumption, secondary industry consumption, tertiary industry consumption and household consumption. In Qinghai Statistical Yearbook, its primary energy consumption comprises four kinds of energy: coal, crude oil, natural gas and hydropower. However, Qinghai government had planned to make full use of its abundant solar and wind resource and these kinds of renewable energy will have a big growth in the future, so we take these kinds of new energy and hydropower as clean energy in primary energy consumption. Fossil energy is the main source of CO₂ emission, and the amount of total carbon dioxide emissions will be calculated. Besides, the energy gap will also be examined and this will provide some meaningful suggestion for Qinghai's energy balance.

2.2. Major policy categories in Qinghai

Qinghai's major economic and social policies and energy policies are documented in two files: "the 12th Five-Year Plan of National Economy and Social Development of Qinghai" (File 1) and "Views of Qinghai Provincial Government on Strengthening Energy-saving Work during 12th Five-Year period" (File 2). We divided all these policies into three subcategories: economic and social development policy, energy development policy, and energy saving policy.

The main goals of these policies are as follows:

- Economic and social development policy: RDP's growth rate reaches 7% per year; the value added of the province's agriculture and animal husbandry industry's average annual growth rate reaches more than 4%; the average annual growth rate of Qinghai's industrial value added is about 15%; the value added of service industry's average annual growth rate reaches 12%. (Documented in File 1)
- Energy development policy: By 2015, the production of coal, crude oil and natural gas will reach 20 million tonnes, 3 million tons and 9 billion cubic meters, respectively. The production of renewable power will account for 40% of all the energy production in Qinghai; hydropower installed capacity in Qinghai will reach 14 million

kilowatts; new energy installed capacity and thermal power will reach more than 2 and 4 million kilowatts, respectively. (Documented in File 1)

- Energy saving policy: The total average energy intensity aims to decrease by 10% and the energy consumption of enterprises above designated size aims to decrease by 16%. (Documented in File 2)

2.3. Scenarios for policy analysis on the energy development

In order to investigate the effects of all three kinds of policies on Qinghai's economy, energy and environment, five different scenarios are described in detail as follows:

- Scenario BS: Baseline Scenario. Over 2011- 2015 period, RDP's growth rate will reach 7% per annum and the growth rate of population of urban and rural will reach 3.5%,-1.2% per annum, respectively. The structure of the economy, the energy intensity of the economy and primary energy consumption structure will be the same with that in 2010, while household consumption will increase at the average growth rate during 2006-2010 periods.
- Scenario IRS: Industrial Restructuring Scenario. Based on the baseline scenario, RDP's growth rate will reach 7% per annum, while the primary industry, industry and tertiary industry's growth rate will reach 4%, 15%, 12% per annum, respectively. So the economy structure will change. The other variables, such as population, primary energy consumption structure and energy intensity, are the same as baseline scenario.
- Scenario HESS: High Energy-Saving Scenario. Based on the baseline scenario, the energy intensity of industry will reduce by 3.43% per annum and will complete the target of 16% decrease in industry energy intensity put forward in Qinghai's energy-saving plan.
- Scenario HCPS: High Clean Energy Producing Scenario. Based on the baseline scenario, the clean energy will account for 40% of the primary energy, while the structure of fossil energy is the same with that in 2010.
- Scenario CS: Composite Scenario. Based on the former four scenarios, this composite scenario tries to examine the implement of both economic and energy development policy on Qinghai's energy balance and environment.

The scenario simulation is demonstrated by using Vensim5.0 software and the parameters of system dynamic model (Fig 2) will be adjusted according to Table 1.

Table 1 key variables description in five scenarios

Scenarios	Economy structure	Energy intensity	Energy consumption
BS	Rem.	Rem.	Rem.
IRS	<i>Cha.</i>	Rem.	Rem.
HESS	Rem.	<i>Cha.</i>	Rem.
HCPS	Rem.	Rem.	<i>Cha.</i>
CS	<i>Cha.</i>	<i>Cha.</i>	<i>Cha.</i>

Notes: 'Rem.' indicates that the factor remains the situation of the base year; '*Cha.*' indicates that the factor changes.

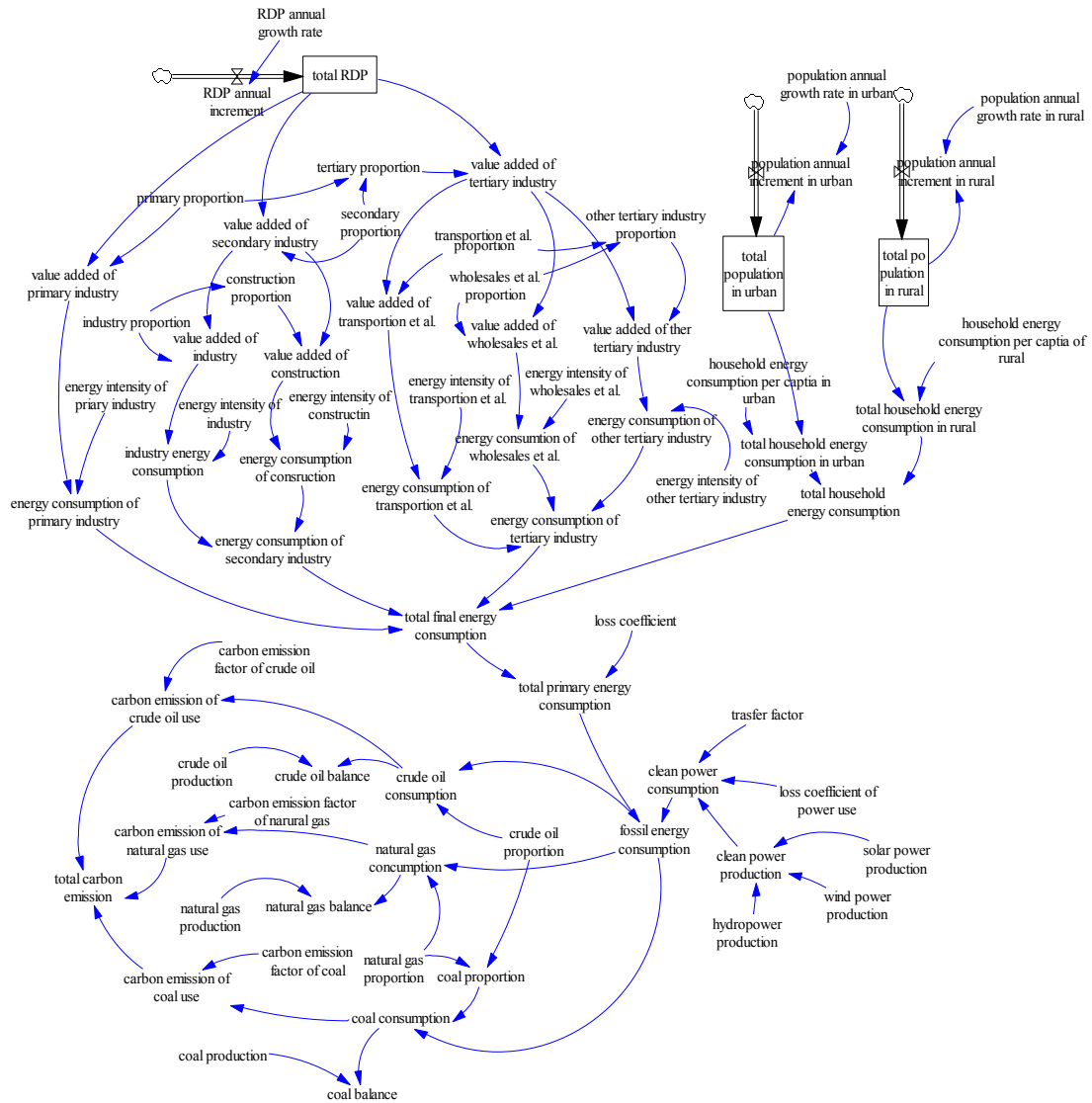


Fig. 2. System dynamics model of policy analysis on Qinghai's energy development

3. Empirical results

3.1. Data

Primary data used in this paper are mainly obtained from Qinghai Statistical Yearbook 2011, and the data of energy intensity are computed based on industrial value added (in 2010 price) and final energy use in each sector. The economy growth rate and energy production are obtained from Qinghai file “the 12th Five-Year Plan of National Economy and Social Development of Qinghai”. Loss coefficient between final energy consumption and primary consumption is calculated based on 2010 data.

Qinghai's RDP will rise to 237.99 billion RMB by 2015 at the annual average growth rate of 7%, an increase of 76.23% over the 12th Five-Year Plan period. In Scenario IRS if all the targets of the economy put forward in the 12th Five-Year Plan can be completed, Qinghai's economy structure will have a big change between primary industry and secondary industry (Fig 3).

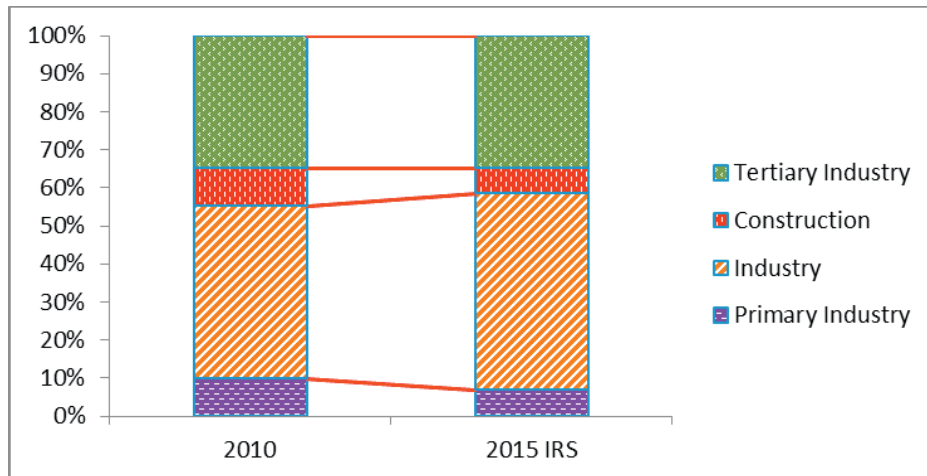


Fig.3. The change of Qinghai's economy structure between 2010 and 2015

The proportion of primary industry will fall from 10% in 2010 to 6.9% in 2015, while the proportion of secondary industry will increase from 55.1% to 58.2%, and the proportion of tertiary industry will be the same with that in 2010. The faster growth in industry will make the proportion of industry in RDP rise from 45.4% to 51.9%, so Qinghai's industry value added will be reach 138.58 billion RMB, more than half of the province's RDP by 2015.

Over 2011- 2015 period, the continuous results of Qinghai's RDP, energy consumption and CO₂ emission can be obtained by the system dynamic model. The policies related to energy development during the 12th Five-Year Plan will have great impact on Qinghai energy use from 2011 to 2015. Compared with 2010 (the last year of the 11th Five-Year Plan, the energy use was mainly influenced by the policies in the 11th Five-Year Plan), this research focus on the changes of Qinghai's energy and economic system in 2015 (the last year of 12th Five-Year Plan) under the context of the implementation of policies related to energy development during the 12th Five-Year Plan, So the simulation started from 2010, and the simulations were demonstrated to make policies analysis.

3.2. Qinghai's energy balance by 2015

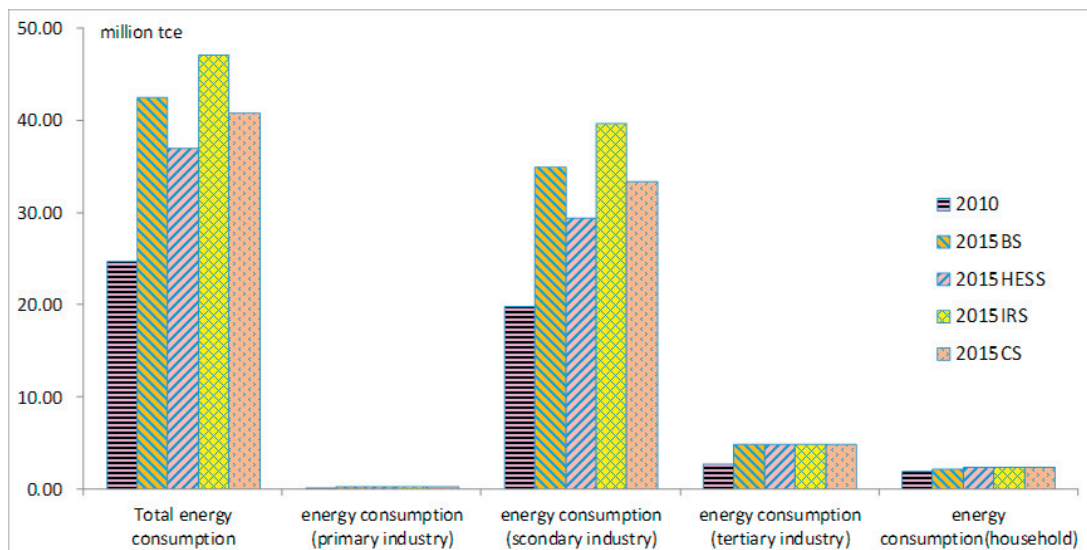


Fig.4. Terminal energy consumption projection results of Qinghai in 2015

It can be observed that total energy consumption has the biggest increase under Scenario IRS (Fig 4). Compared with the Scenario BS, a reduction of 16% in industry energy intensity will have significant effects on energy conservation in Scenario HESS. As a result, the energy intensity of RDP will decrease by 6.3%, which cannot satisfy the goal of 10% reduction in Qinghai's energy intensity, so improving the energy efficiency in other parts is also in need. In Scenario IRS, the rapid growth of industry will bring a big increase in energy consumption consuming more than 4.6 million tce compared with Scenario BS. In all scenarios, energy consumption in secondary industry is the largest, which accounts for about 80% of the total energy consumption. If high energy-saving policy is carried out efficiently when the economy experiences a big change, Qinghai's final energy use in Scenario CS will reach 42.44 million tce, saving 1.67 million tce compared with Scenario BS. Qinghai is experiencing rapid industrialization and its economic structure is dominated by secondary industry. In 2011 it accounted for 58.4% of the RDP, and the tertiary industries accounted for 32.3%. To improve energy efficiency in the long run, a change in the economic structure is deemed necessary.

When energy demand and supply are both known, we can investigate the energy balance. In Qinghai's 12th Five-Year Plan, it put forward a target that the production of coal, crude oil and natural gas would reach 20 million tons, 3 million tons and 9 billion cubic meters by 2015, respectively. The units of energy in all scenario simulations are tons of standard coal equivalents, and according to the conversion factor between standard coal equivalent and coal, crude oil, natural gas, the result of disaggregated energy can be changed into physical volume. The energy balance of Qinghai in 2015 is presented in Fig.5.

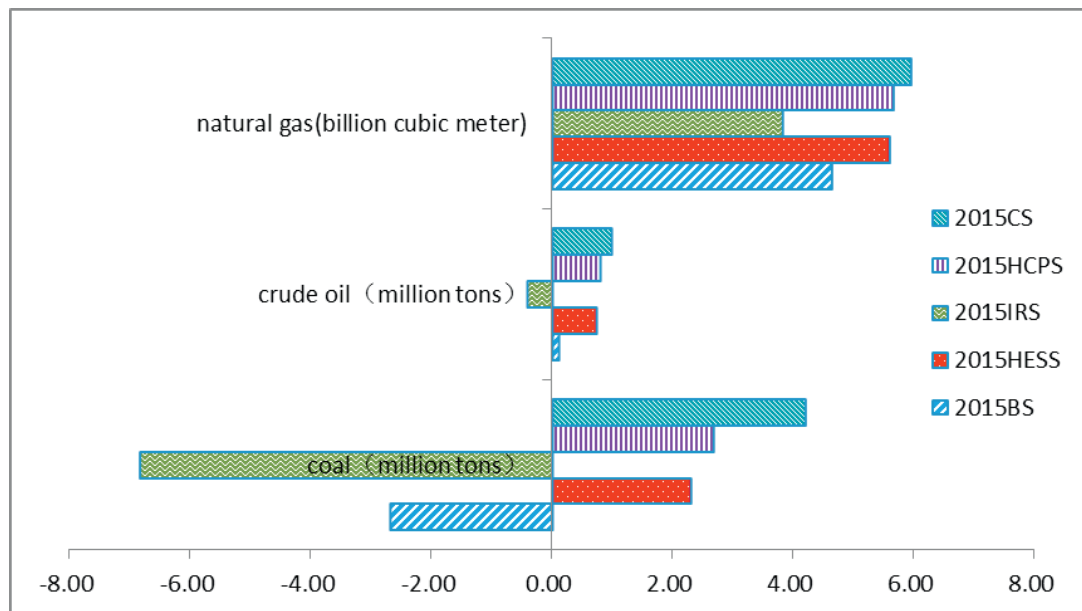


Fig.5. The fossil energy balance of Qinghai in 2015

The values in Fig. 5 are obtained by using energy consumption minus energy production in physical quantity, so the negative value means that the energy supply cannot satisfy energy demand. From Figure 5, Qinghai will be short of crude oil and coal in Scenario IRS, while its coal demand will be more than its supply by 2.7 million tons in Scenario BS. In Scenario HESS and Scenario HEPS simulation, Qinghai's energy supply will be surplus its consumption, which suggests that the energy-saving policies and clean energy development policies have significant impacts on Qinghai's energy balance. Besides, it is easily found that natural gas balance value is positive in any scenario simulation, indicating that Qinghai can increase natural gas consumption to replace other scarce energy resources in economic and social development. Qinghai Province has abundant natural gas resources and solar energy resources, so it should promote the clean energy production and adjust its energy consumption structure.

3.3. CO₂ emission by 2015

In this research, it is supposed that the relative proportion among coal, crude oil and natural gas keeps stable and is the same with that in 2010. CO₂ emission mainly comes from coal-burning, which accounts for 70% of the total emission caused by fossil fuel. Compared with Scenario BS and Scenario IRS, the amount of CO₂ emission has big decrease in Scenario HESS and Scenario HCPS, which can be ascribed to the reduction of total energy consumption and the increasing proportion of clean energy in energy use (Fig.6). In Scenario CS, total CO₂ emission only increase by 34.15% when Qinghai's RDP has an increase of 76.23%, indicating that energy saving policy and clean energy development play a significant role on environment protection.

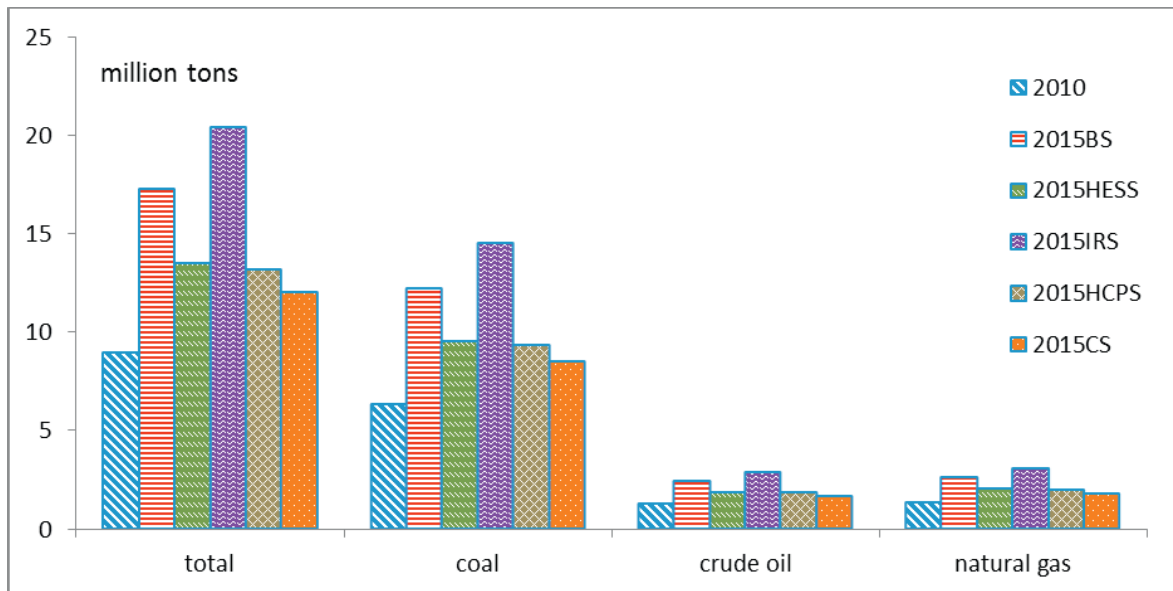


Fig.6. The amount of CO₂ emission comes from fossil energy use in 2015

4. Conclusions

On the context of the 12th Five-Year Plan, most provinces' energy developments are faced with the dual pressures to support the rapid economy development and energy conservation. The pressure is severer for western developing provinces. Various policies are put forward at the provincial level to coordinate the energy development and economy development. Taking Qinghai Province as an example, this paper proposes a framework of economy and energy system including three major components: economy growth, population and energy intensity to identify the regional energy balance and CO₂ emission by 2015, and five different scenario simulations are demonstrated to find out how Qinghai's economy and energy development policies will influence its economy, energy balance and environment. The research results show that Qinghai's RDP and energy demands will increase by 76.23% and 90.37% respectively by 2015. At the same time, Qinghai's industrial structure will have a big adjustment especially that the rapid development of energy-consuming industries in the secondary industry will greatly increase Qinghai's energy demands. While the efficient implement of energy saving and emission reduction policies will play a significant role in energy saving and energy balance. Besides, increasing production of clean energy can greatly decrease the consumption of fossil fuels, reducing the environmental impact.

Acknowledgments:

This research is supported by the National Natural Science Foundation of China (No.71003091 and 71133005), the Energy Foundation (G-1009-13333), Key Research Program of Institute of Policy and Management, Chinese Academy of Sciences (Y201171Z01 and Y201151Z02), and Youth Innovation Promotion Association of the Chinese Academy of Sciences.

References

- [1] Crompton P, Wu Y. Energy consumption in China: past trends and future directions. *Energy Economics* 2005; 22:569-586.
- [2] Li J, Tang L, Sun X, Wu D. Oil-importing Optimal Decision Considering Country Risk with Extreme Events: A Multi-Objective Programming Approach. *Computers & Operations Research*. DOI: 10.1016/j.cor.2011.10.010
- [3] Fisher-Vanden K, Jefferson GH, Liu H, Tao Q. What is driving China's decline in energy intensity? *Resource and Energy Economics* 2004; 26:77-97.
- [4] Tang L, Yu L, Wang S, Li J, Wang S. A novel hybrid ensemble learning paradigm for nuclear energy consumption forecasting. *Applied Energy* 2012;93: 432 – 443.
- [5] Sun X, Li J, Wu D, Yi S. Energy Geopolitics and Chinese Strategic Decision of the Energy Supply Security: A Multiple-Attribute Analysis. *Journal of Multi-Criteria Decision Analysis* 2011; 18: 151–160.
- [6] Fan Y, Liao H, Wei Y. Can market oriented economic reforms contribute to energy efficiency improvement? Evidence from China. *Energy Policy* 2007, 35(4), 2287-2295
- [7] Cai S, Mou D, Fang M. A study on driving forces of China's industrial structure optimization under the carbon-intensity abatement objective. *Chinese Journal of Management Sciences* 2011,19(4), 167-173.(in Chinese)
- [8] Cai S, Du L, Bi Q. Improvement target of energy efficiency and its design. *Chinese Journal of Management Sciences* 2012,20(3), 152-160.(in Chinese)
- [9] Singh S, Singh IP, Singh S, Pannu CJS. Energy planning of Punjab village using multiple objectives compromise programming. *Energy Conversion and Management* 1996; 37(3), 329-342.
- [10] Ediger VS, Akar S. ARIMA forecasting of primary energy demand by fuel in Turkey. *Energy Policy* 2007; 35(3):1701–1708.
- [11] Ermis K, Midilli A, Dincer I, Rosen MA. Artificial neural network analysis of world green energy use. *Energy Policy* 2007; 35(3):1731–1743.
- [12] Wei Y, Liang Q, Fan Y, Okada N, Tsai HT. A scenario analysis of energy requirements and energy intensity for China's rapidly developing society in the year 2020. *Technological Forecasting and Social Change* 2006; 73(4):405–421.
- [13] Jiang B, Chen W, Yu Y, Zeng L, Victor D. The future of natural gas consumption in Beijing, Guangdong and Shanghai: an assessment utilizing MARKAL. *Energy Policy* 2008; 36(9), 3286-3299.
- [14] Ford A, Bull M. Using system dynamics for conservation policy analysis in the Pacific Northwest. *System Dynamics Review* 1989; 51(1), 1-16.
- [15] Naill RF. Managing the energy transition: A system dynamics search for alternatives to oil and gas. Ballinger Publishing Company; 1977.